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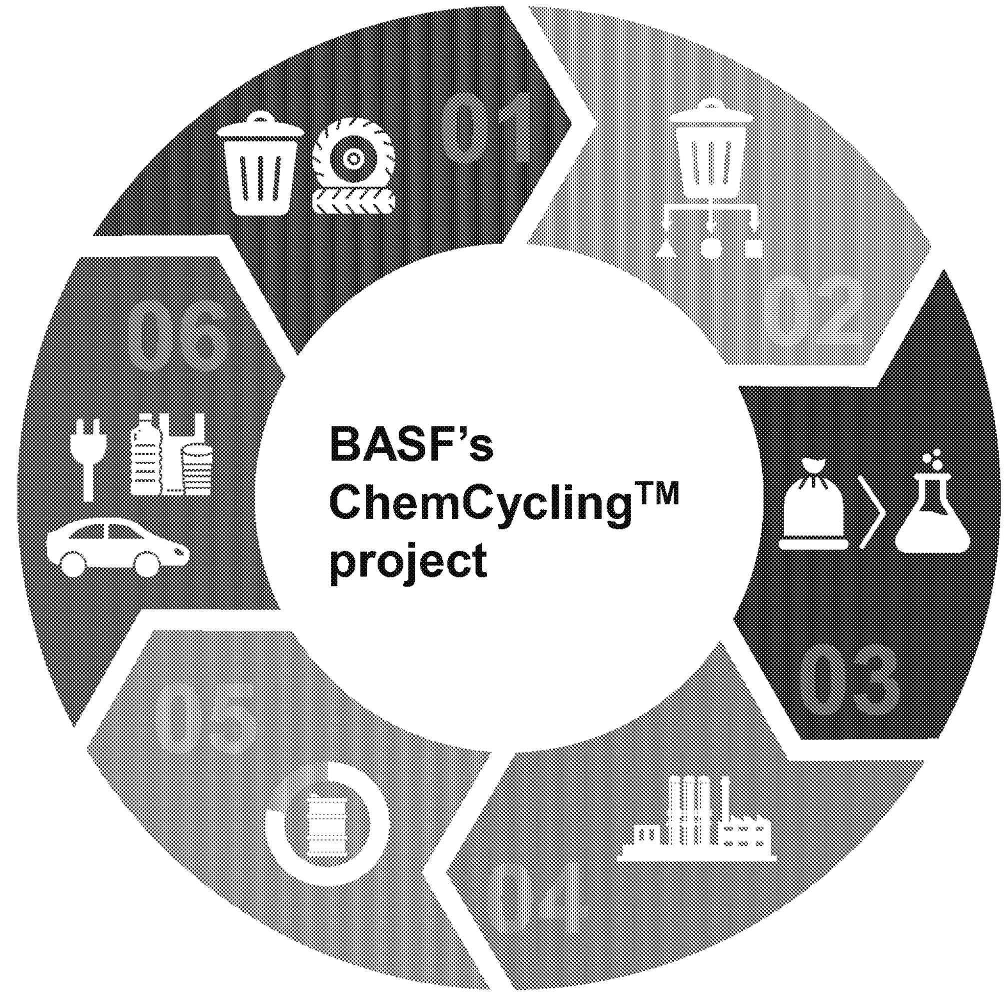
ChemCycling™: Environmental Evaluation by Life Cycle Assessment (LCA)

Ludwigshafen, May 2020



Life Cycle Assessment (LCA) ChemCycling™

Methodological approach

Target: Environmental assessment of chemically recycled products by comparing different end-of-life options for mixed plastic waste* and virgin plastics production

The LCA study comprises **three separate studies** considering waste, product and plastic quality perspectives

The LCA study was **performed by a third party according to ISO 14040/44** and was **reviewed by three independent experts**

Where available, the LCA was **calculated with high-quality data from existing commercial plants**

* Mixed plastic waste from German yellow bag (= post-consumer packaging waste)

Life Cycle Assessment (LCA) ChemCycling™
Conformity to respective ISO 14040 series

Three separate studies

- **Waste perspective:** Comparison of pyrolysis and incineration of mixed plastic waste
- **Product perspective:** Comparison of plastics based on pyrolysis oil and conventional plastics from primary fossil resources (naphtha)
- **Plastics quality perspective:** Comparison of the life cycle of 1t of virgin plastics with three end-of-life options

Panel decision

- **"…the LCA study followed the guidance of and is consistent with the international standards for Life Cycle Assessment (ISO 14040:2006 and ISO 14044:2006)."**
- Upon request the review statement is available from the study commissioner

Commissioner / LCA practitioner

Dr. Christian Krüger

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Manfred Russ

sphera™
Advancing Operational Excellence™

Critical Review Panel

Prof. Adisa Azapagic
(Panel Chair)

ETHOS Research
Environment · Technology · Society

Dr. Florian Antony

Öko-Institut e.V.
Institut für angewandte Ökologie
Institute for Applied Ecology

Simon Hann

eunomia

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Excursus: Pyrolysis

An efficient process to convert mixed plastic waste into a secondary raw material for the chemical industry

About 70% of the mixed plastic waste can be converted into pyrolysis oil

Almost no external thermal energy used: Pyrolysis gas generates the energy required for the process

Only a small amount of the input materials are residues and must be incinerated

Plastics based on pyrolysis oil can achieve 100% identical quality as fossil-based plastics*

Mixed plastic waste** → **Pyrolysis**

Energy → **Pyrolysis**

Pyrolysis → CO_2

Pyrolysis → **Pyrolysis oil** → **Purification**

Pyrolysis → Char

Purification → **Naphtha substitute** →

Purification → Side product

→ Suppliers | **BASF** →

* under application of a mass balance approach

** from a sorting plant

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LCA ChemCycling™
General results

Chemical recycling is attractive in terms of CO_2 emissions

- Pyrolysis of mixed plastic waste emits 50 percent less CO_2 than incineration of mixed plastic waste

- CO_2 emissions are saved when manufacturing plastics based on pyrolysis oil (as secondary raw material under a mass balance approach) instead of naphtha (primary fossil raw material). The lower emissions result from avoiding the incineration of mixed plastic waste

- Manufacturing of plastics via either chemical recycling (pyrolysis) or mechanical recycling of mixed plastic waste results in comparable CO_2 emissions. It was taken into account that the quality of chemically recycled products is similar to that of virgin material and that usually less input material is sorted out than with mechanical recycling

LCA study 1

Waste perspective

Does pyrolysis of mixed plastic waste save CO_2 emissions compared to incineration?

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Comparison of CO_2 emissions between pyrolysis and incineration of mixed plastic waste

Case study comprises cradle-to-gate life cycle for the different end-of-life options of 1t of mixed plastic waste

Input

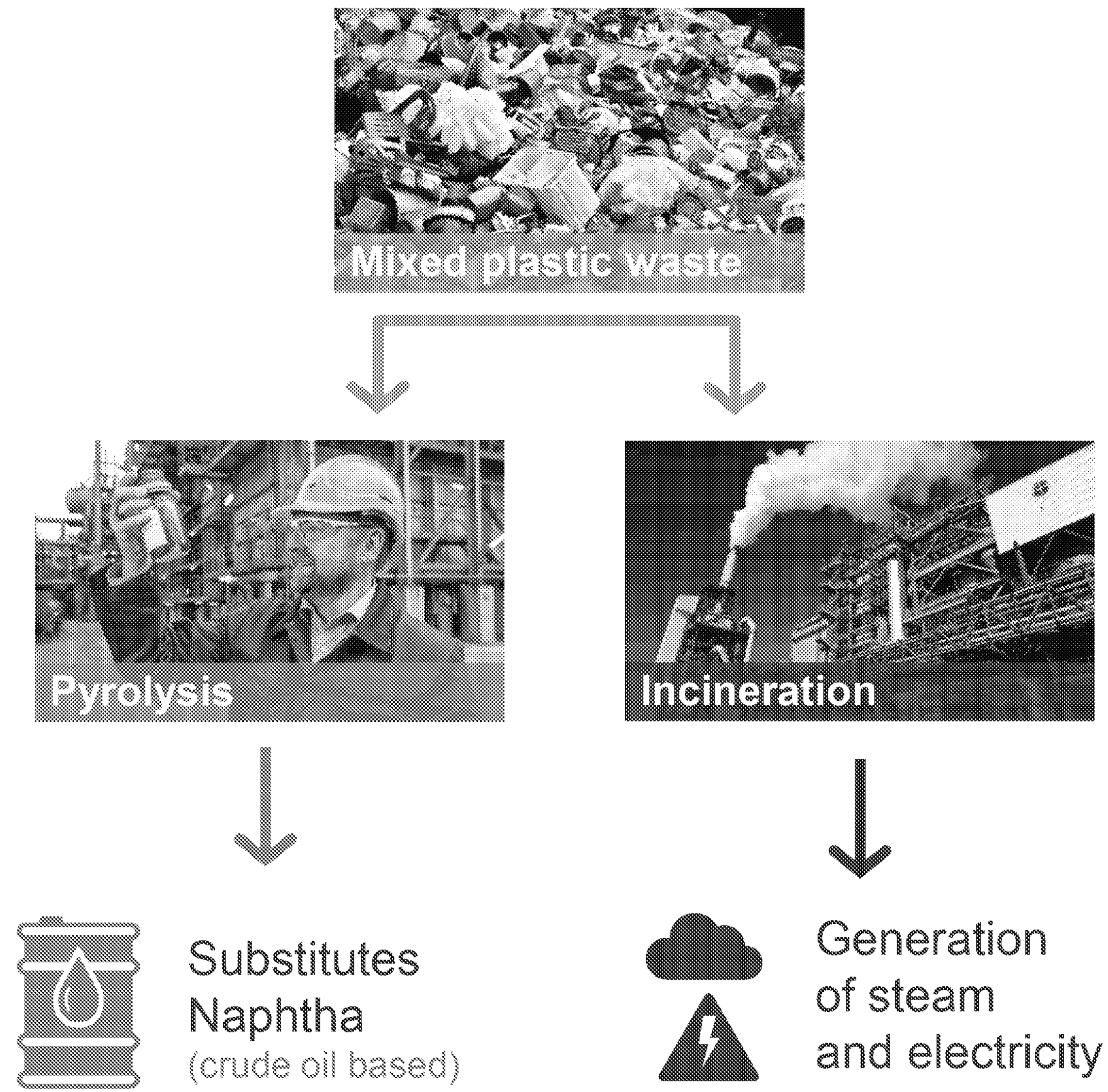
- 1t mixed plastic waste from packaging (German yellow bag)

Process alternatives

- Pyrolysis incl. pretreatment and purification
- Incineration (MSWI, RDF)*

Output

- Pyrolysis: Efficient production of oil as feedstock for the chemical industry (material yield: 70%, almost no need of external energy due to internal energy recovery)
- Incineration: Generated electricity and steam substitutes electricity from national grid and steam from national average (light fuel oil and natural gas)



* MSWI = municipal solid waste incineration;
RDF = refuse derived fuel (no coal-fired and cement plants)

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Comparison of CO_2 emissions between pyrolysis and incineration of mixed plastic waste

Results

- **Pyrolysis of mixed plastic waste emits 50 percent less CO_2 than incineration of mixed plastic waste**
- Specifically, the study found that pyrolysis emits 1 ton less CO_2 than incineration per 1 ton of mixed plastic waste

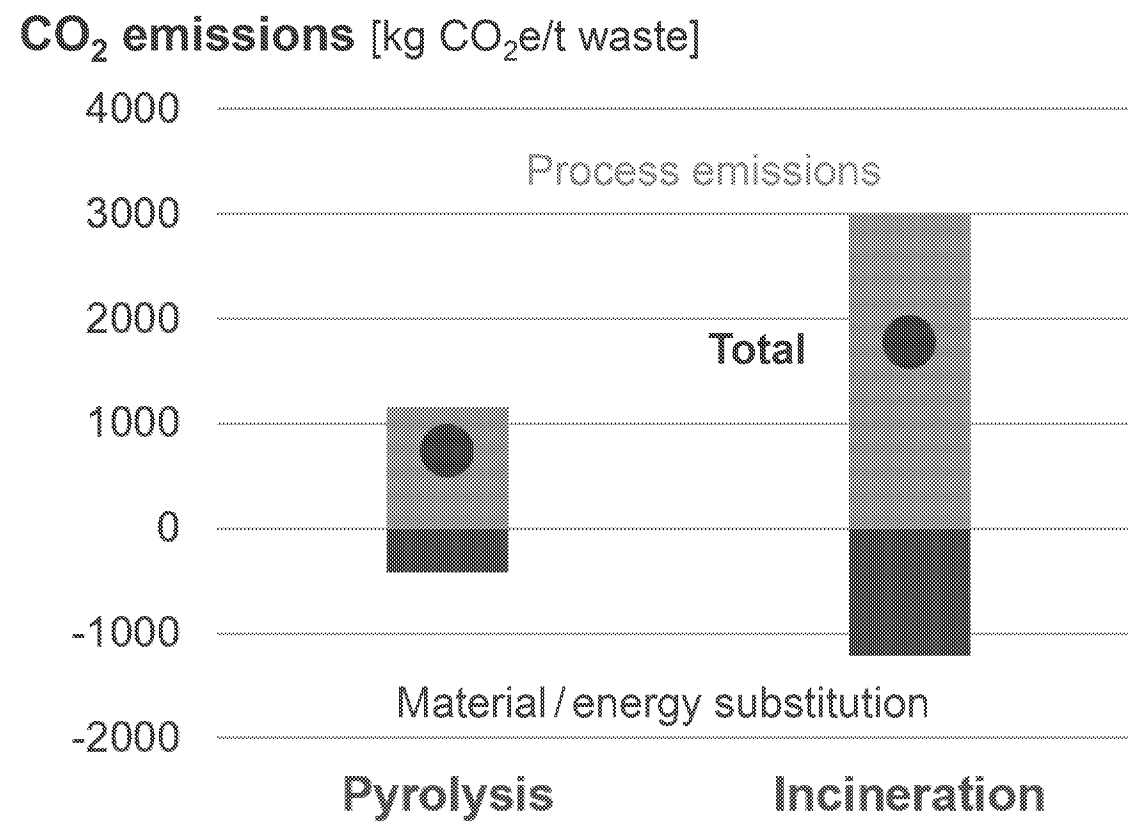

Fig. 1: Pyrolysis of 1t mixed plastic waste emits, in total, 739 kg CO_2e.
Incineration of 1t mixed plastic waste emits, in total, 1777 kg CO_2e.

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Comparison of CO_2 emissions between pyrolysis and incineration of mixed plastic waste

Explanations

- Pyrolysis emits less direct emissions than incineration (light green bars)
- If all CO_2 emissions and savings are taken into account, both alternatives receive credits (dark green bars):
  - Pyrolysis: CO_2 savings credited as pyrolysis oil is replacing fossil feedstock in chemical production
  - Incineration: CO_2 savings credited the energy generated by incineration which replaces the average energy sourced from the national grid

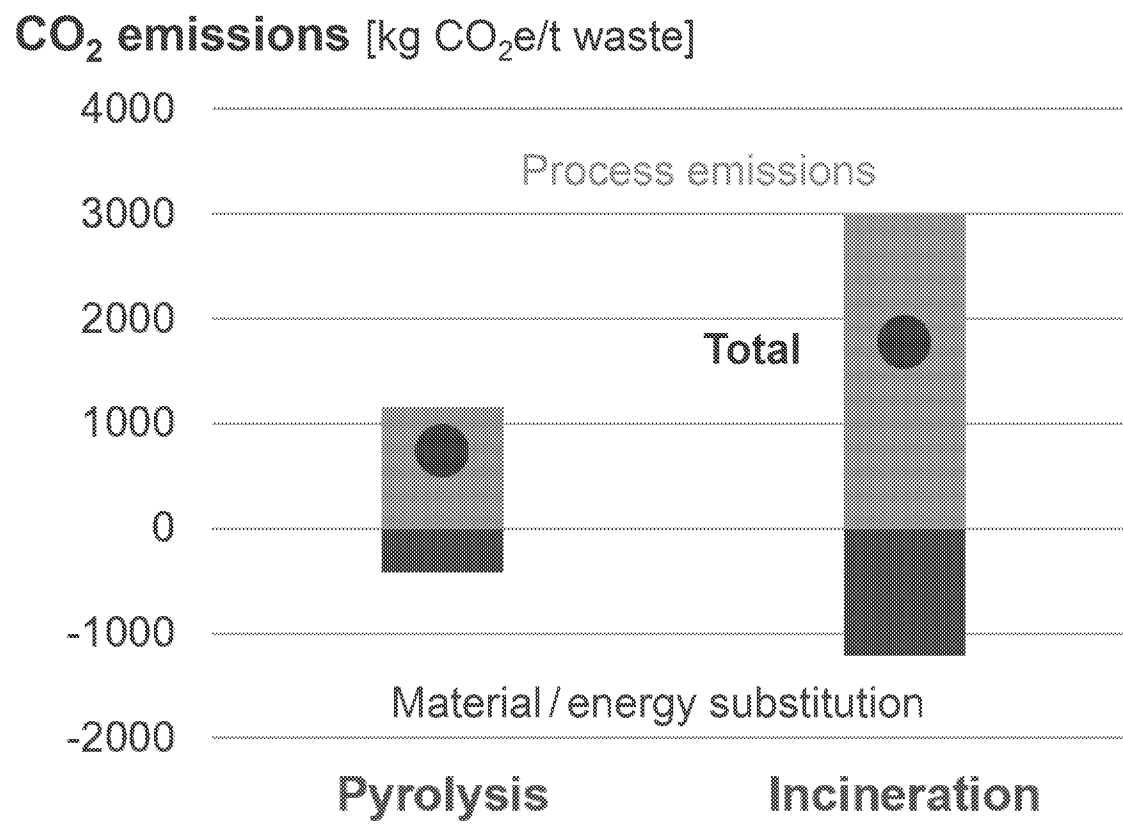

Fig. 1: Pyrolysis of 1t mixed plastic waste emits, in total, 739 kg CO_2e.
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LCA study 2

Product perspective

Does plastic material based on waste pyrolysis oil cause lower CO_2 emissions than plastic material produced with fossil naphtha?

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Comparison of CO_2 emissions between plastics production from pyrolysis oil and naphtha

Case study comprises cradle-to-gate life cycle
for the production of 1t of plastic product

Input

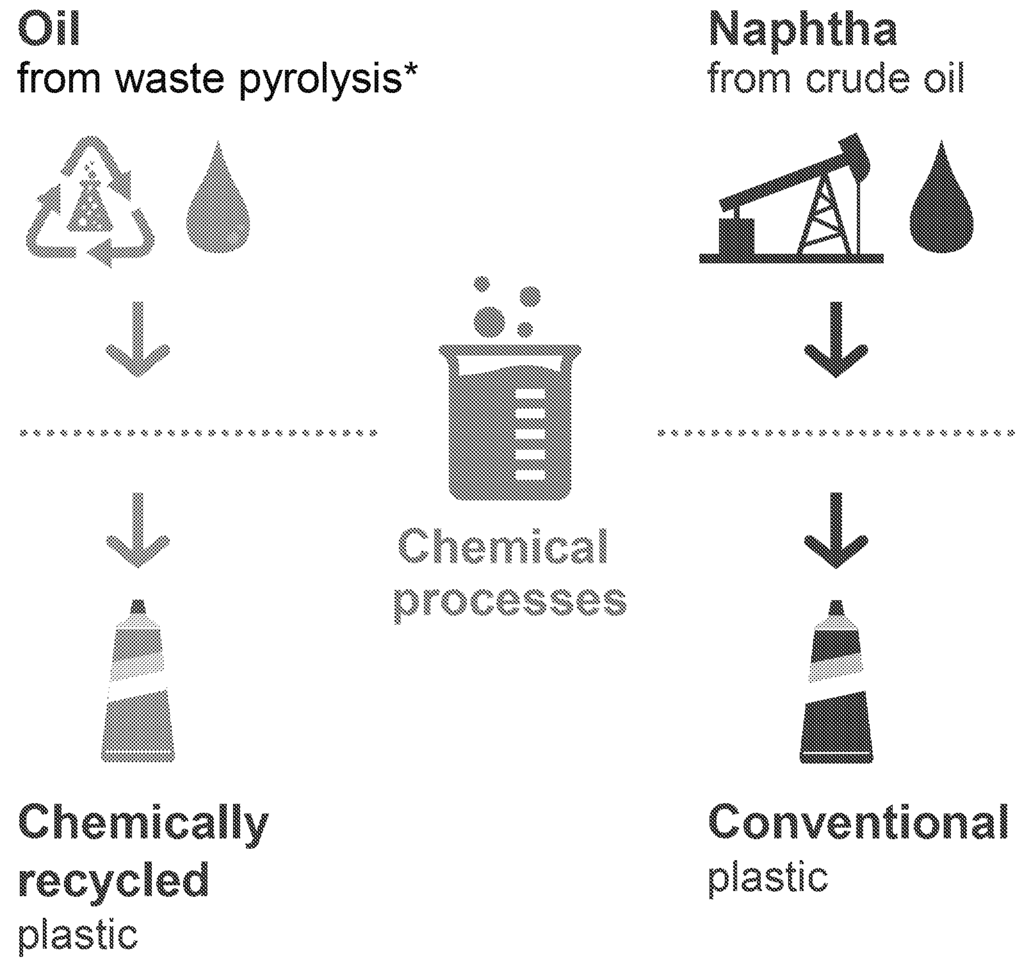
- Oil from pyrolysis of mixed plastic waste (German yellow bag)
- Naphtha from crude oil

Processes

- Production of ethylene in steam cracker and polymerization to LDPE (low-density polyethylene)

Output

- Chemically recycled: LDPE (from pyrolysis oil)
- Conventional: LDPE virgin (from naphtha)



* Including the life cycle steps of study 1

Comparison of CO_2 emissions between plastics production from pyrolysis oil and naphtha

Results

- **CO_2 emissions are saved when manufacturing plastics based on pyrolysis oil under a mass balance approach instead of naphtha. The lower emissions result from avoiding the incineration of mixed plastic waste**
- In particular, the study could show this for the production of a reference plastic (LDPE): 1 ton of LDPE produced from pyrolysis oil under a mass balance approach, emits 2.3 t less CO_2 than 1 ton LDPE produced from fossil naphtha

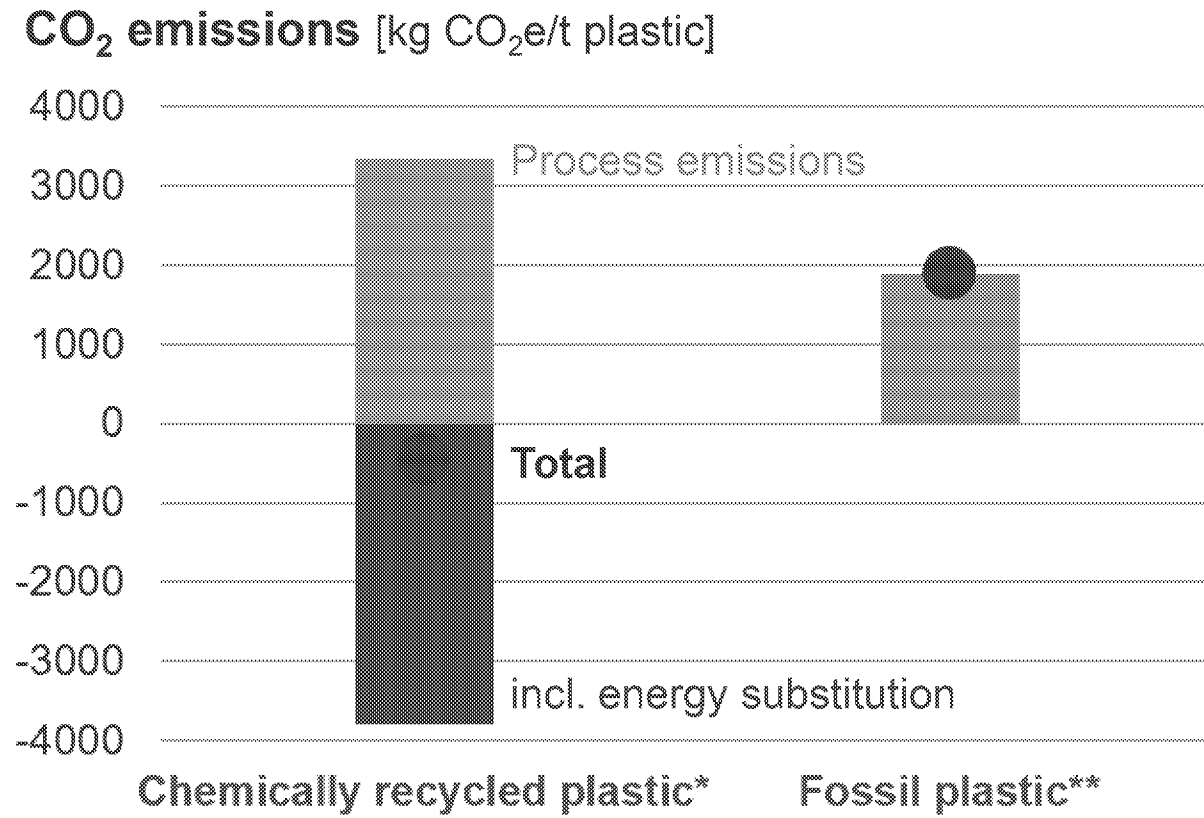


Fig. 2: Conventional production of 1t LDPE emits, in total, 1894 kg CO2e. For the production of 1t LDPE via pyrolysis a negative number of -477 can be accounted for the overall CO_2 emissions.

* pyrolysis used as chemical recycling technology
** from primary fossil resources

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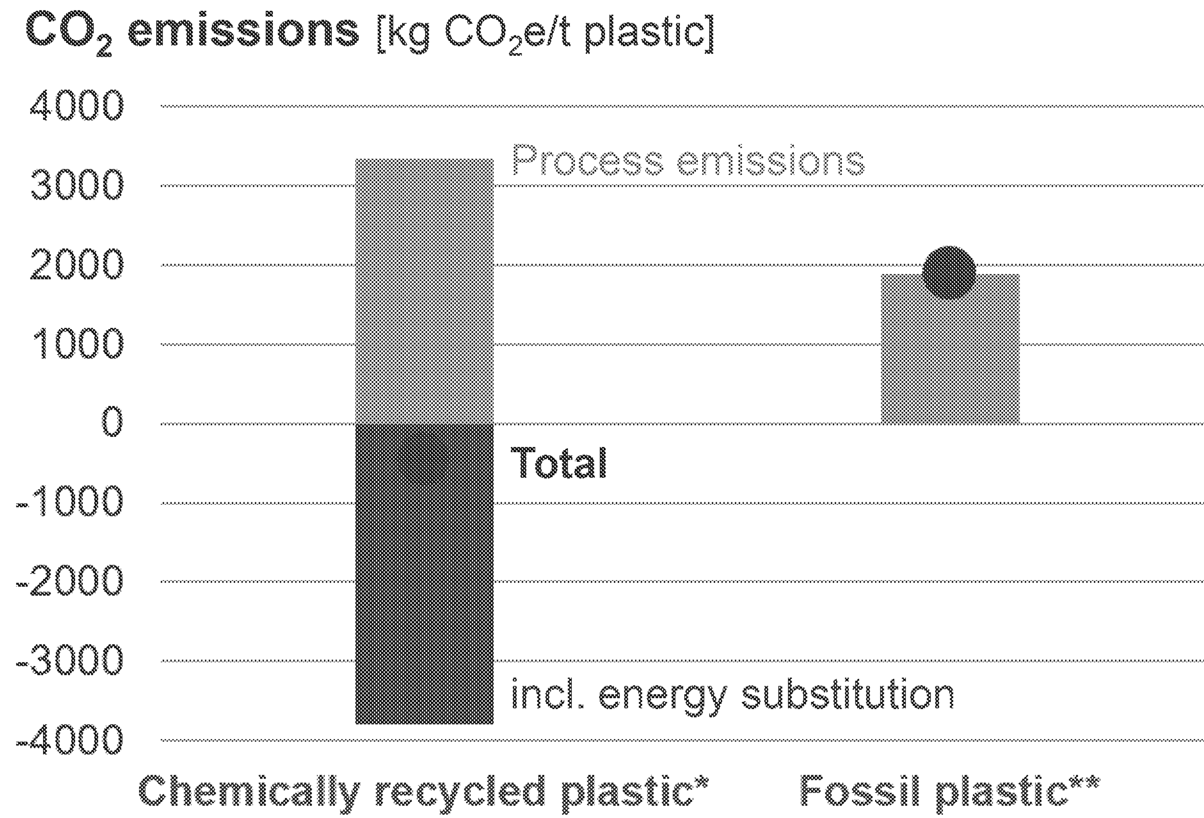
Comparison of CO_2 emissions between plastics production from pyrolysis oil and naphtha

Explanations

- Direct emissions of chemically recycled plastics are higher than for virgin plastics due to the extremely efficient fossil naphtha supply chains (light green bars)
- However, CO_2 savings that originate from not incinerating the plastic waste can be credited to the chemically recycled plastic (dark green bars)
- In total, a net overall advantage of chemically recycled plastic compared to fossil



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** from primary fossil resources

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LCA study 3

Plastic quality perspective

Does plastic material produced via chemical recycling cause lower CO_2 emissions than plastic material produced via mechanical recycling?

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Comparison of CO_2 emissions of 1t of virgin plastics with three end-of-life options

Case study comprises life cycle from 1t of fossil plastic and three different end-of-life options incl. production of secondary material (reflecting composition of the German yellow bag)

Input

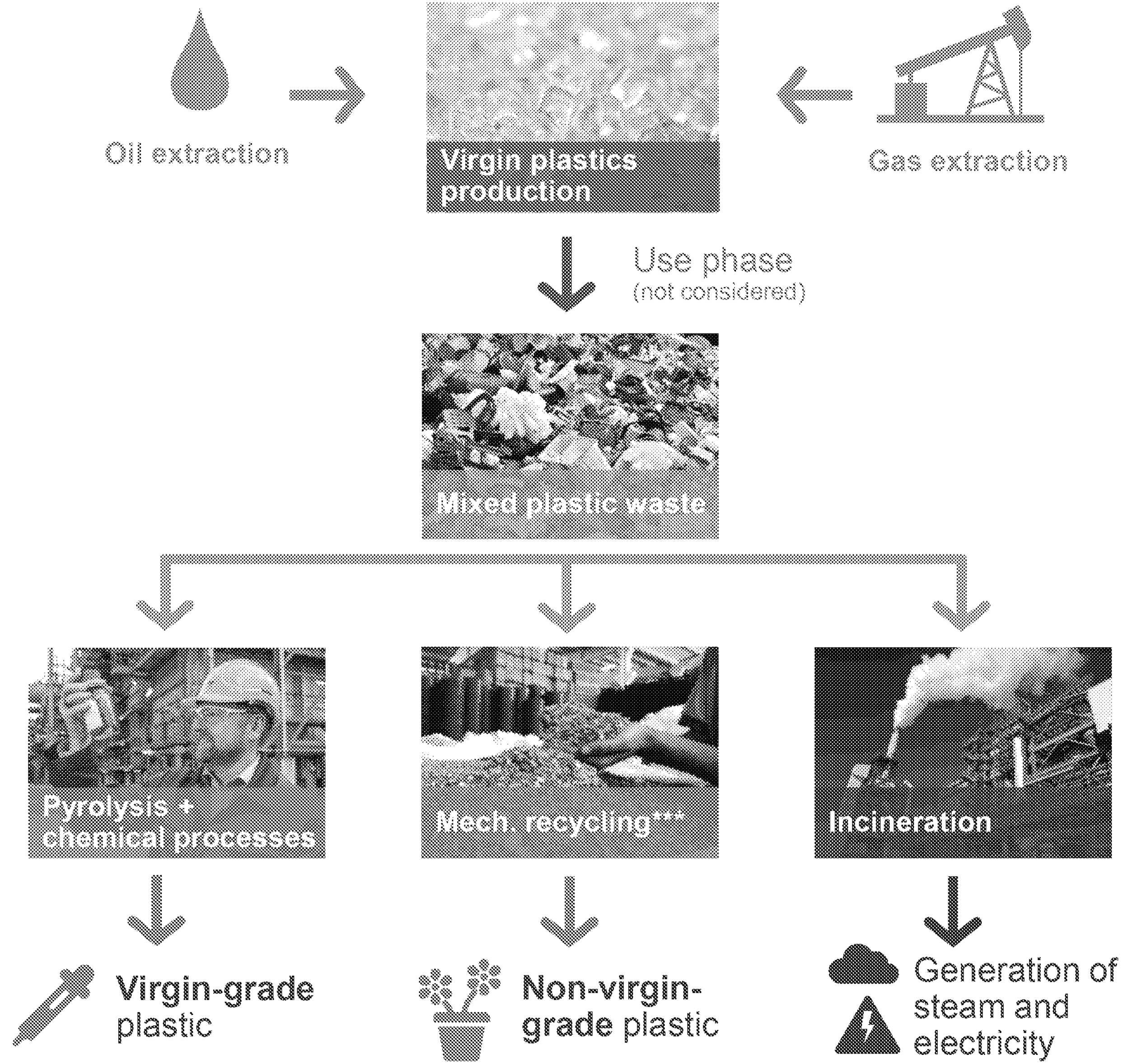
- Virgin plastics production based on oil & gas turned into mixed plastic waste

Process alternatives

- Pyrolysis (incl. pretreatment, purification and incineration of sorting losses) + chemical processes; applying mass balance approach
- Mechanical recycling (incl. pretreatment, extrusion and sorting losses)
- Incineration (MSWI, RDF)*

Output

- Pyrolysis produces high-performance virgin-like plastics
- Mechanical recycling produces non-virgin-grade plastics**
- Incineration: Generated electricity and steam substitutes electricity and steam from national grid/average



* MSWI = municipal solid waste incineration; RDF = incineration of refuse derived fuel (no coal-fired and cement plants)

** Product quality factor: 0.5 (from Circular Footprint Formula by EU Commission)

*** Material losses are incinerated

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Comparison of CO_2 emissions of 1t of virgin plastics with three end-of-life options

Results

- Manufacturing of plastics via either chemical recycling (pyrolysis) or mechanical recycling of mixed plastic waste result in similar CO_2 emissions
- It was taken into account that the quality of chemically recycled products is similar to that of virgin material and that usually less input material is sorted out than in mechanical recycling

CO_2 emissions [kg CO_2e/t product]

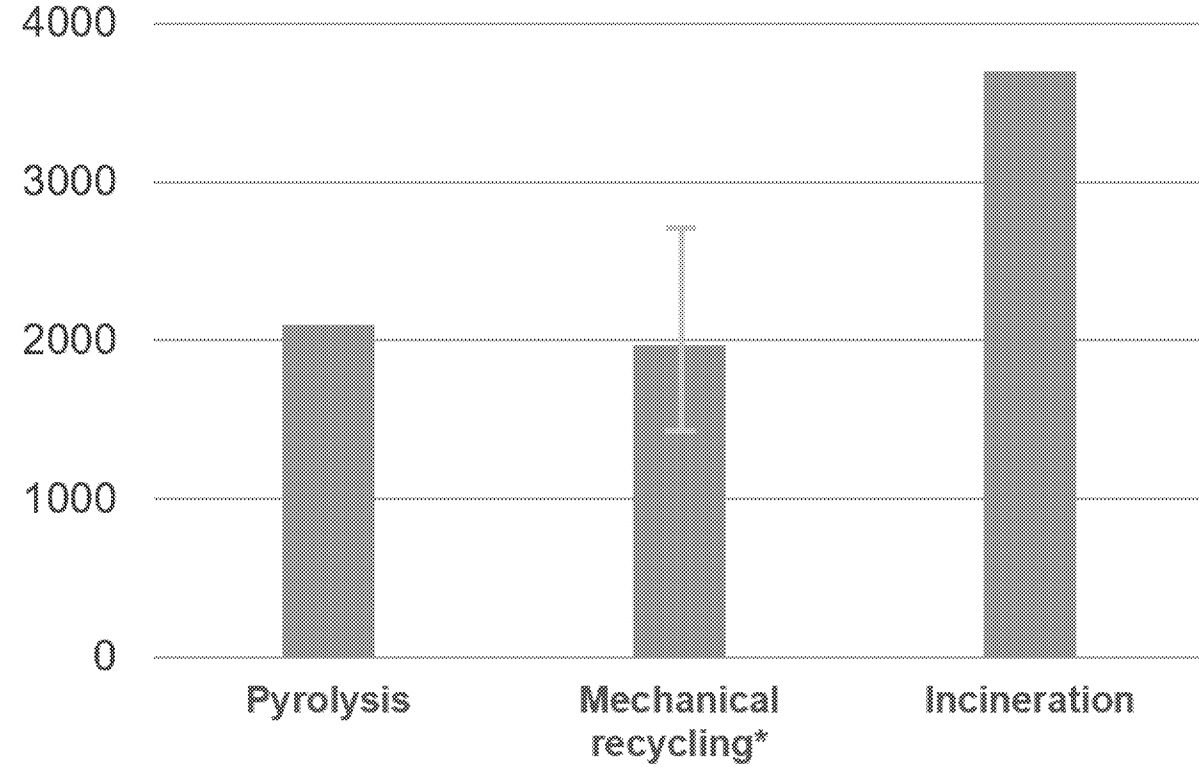

Fig. 3: Production and end-of-life treatment of 1t of plastics via pyrolysis emit 2,100 kg CO2e, whereas production and end-of-life treatment of 1t of plastics via mechanical recycling emits 1,973kg CO2e. Production and incineration of 1t of plastics emits 3,700 kg CO2e.

* The error bar reflects the different scenarios by changing the quality factor and the material loss rates after sorting of waste

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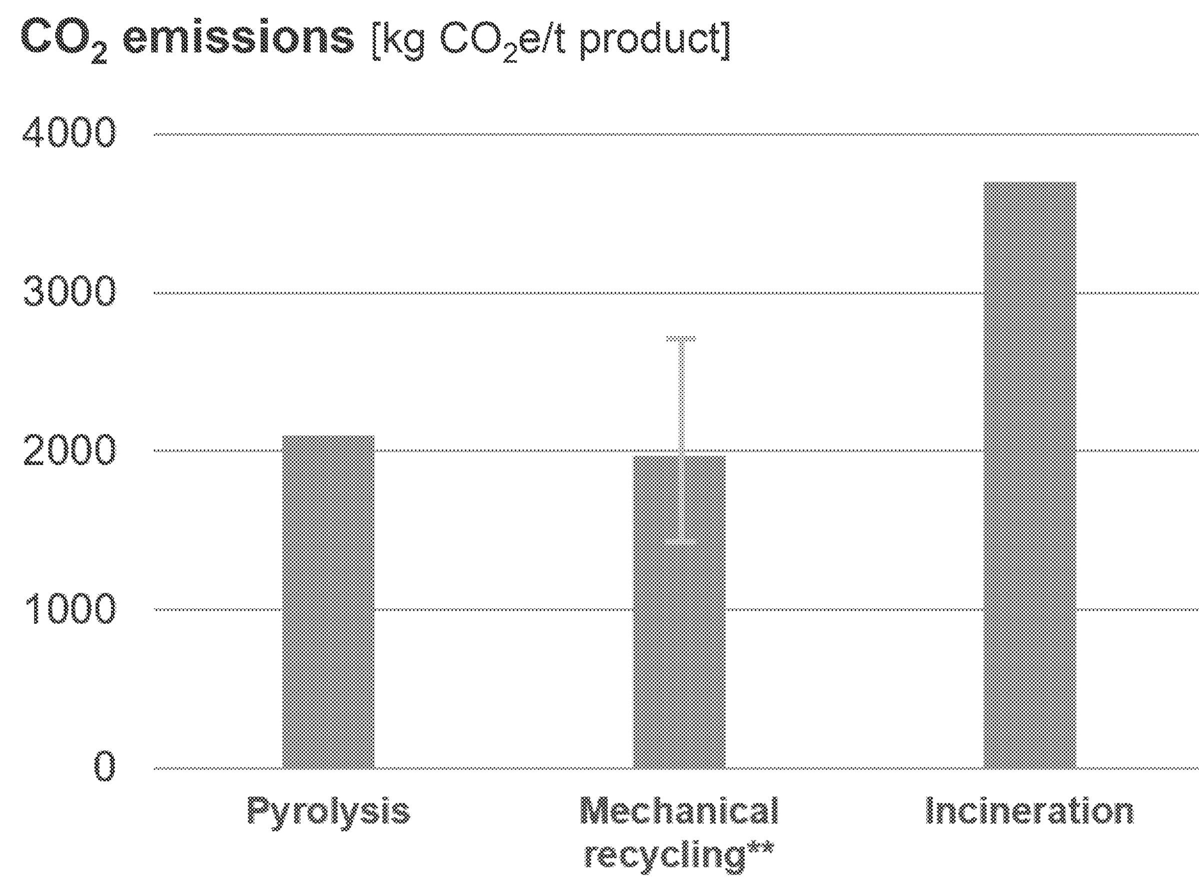
Comparison of CO_2 emissions of 1t of virgin plastics with three end-of-life options

Explanations

- Manufacturing of products with chemically recycled feedstock and with mechanically recycled feedstock emits significantly less CO_2 than virgin fossil products that are incinerated
- To consider the different product qualities for chemical and mechanical recycling the *Circular Footprint Formula* was applied: With chemical recycling original product quality (quality factor = 1) can be achieved. Mechanical recycling of mixed plastic waste results in non-virgin-grade quality; according to economic considerations a quality factor of 0.5 is used
- For pyrolysis the yield is 70%, the material losses for mechanical recycling are up to 55%*

* starting from sorting plant. Source: Öko-Institut / Insitute for Applied Ecology (2016): Umweltpotenziale der getrennten Erfassung und des Recyclings von Wertstoffen im Dualen System



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